EARS Buoy Applications by LADC: II. 3-D Seismic Airgun Array Characterization

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Abstract*-In September 2007 the Littoral Acoustic Demonstration Center (LADC), a consortium of University and Navy scientists, conducted an experiment in the northwest Gulf of Mexico to measure the three-dimensional acoustic field of the primary arrival from a seismic airgun array. The water depth was approximately 1500 m. The acoustic measurements were made by Generation 2 4-channel EARS (Environmental Acoustic Recording System) buoys developed by the Naval Oceanographic Office (NAVOCEANO), with each channel capable of measuring to 25 kHz. A total of 48 hydrophones were deployed on 3 moorings at 20 different depths. At each depth there was a sensitive and desensitized phone, the latter used to prevent clipping. Eight hydrophones (four pairs) were ship-deployed near the surface. A dedicated source ship, the M/V Fairfield ENDEAVOR, supplied almost all the shots, although the M/V Veritas VANTAGE, which was conducting a survey in the area, provided a few lines of opportunity. The M/V CAPE HATTERAS was used to deploy, manage, and recover the receiving hydrophone arrays, as well as to conduct all environmental measurements. It also deployed and provided communication and control for the Ultra Short BaseLine Localization (USBL) system and a single Acoustic Doppler Current Profiler (ADCP), which were used to give accurate hydrophone positions during the experiment. About 3.5 TB of data were collected.

I. INTRODUCTION

The Littoral Acoustic Demonstration Center (LADC) was formed as a consortium of scientists in 2001 to study ambient noise, propagation, and marine mammal acoustics in shallow water using Environmental Acoustic Recording System (EARS) buoys. The consortium now includes scientists from the University of New Orleans, the University of Southern Mississippi, the University of Louisiana at Lafayette, the Applied Research Laboratories of the University of Texas at Austin, the Naval Research Laboratory at Stennis Space Center (NRL-Stennis), and the Naval Oceanographic Office at Stennis (NAVOCEANO). Other scientists have been associated for specific projects.

In the summer of 2003 LADC was asked to conduct a calibration experiment for a 3190-cubic inch 21-element seismic exploration array. Shots were recorded and calibrated to produce absolute broadband (up to 25 kHz) pressure-time dependencies for a wide range of offsets and arrival angles. Two single-channel EARS buoys, one with a desensitized hydrophone to record marine seismic array emissions without clipping the data, were deployed at a depth of 758 m in a water depth of 990 m, near Green's Canyon in the Gulf of Mexico, during June 2003. The M/V KONDOR towed the seismic airgun array on five parallel

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linear tracks with the horizontal closest approach points to the EARS buoy position of 0, 500, 1000, 2000, and 5000 m. The tracks provided a wide range of measured emission angles (6° to 84°, with the 0°-angle corresponding to the vertical) and horizontal ranges up to 7 km from the array center to the EARS buoys. The total number of shots recorded was about 500.

Experimental data were analyzed to obtain maximum received pressure levels (200 dB re 1 μPa) and maximum sound exposure levels (177 dB re 1 μPa^2 sec) for each shot. Experimental data were modeled by using the underwater acoustic propagation model (RAM) and seismic airgun modeling packages (Gundalf and Nucleus) for a variety of offsets and arrival angles. Experimental and simulated data demonstrated good agreement in absolute pressure amplitudes and frequency interference patterns for frequencies up to 800 Hz. A detailed analysis is given by Tashmukhambetov, G. E. Ioup, J. W. Ioup, Sidorovskaia, and Newcomb in [1].

In addition to the discussion of airgun propagation modeling in a shallow water waveguide given in the above-referenced JASA article [1], the following abstracts, articles, and report also discuss the subject: [2] through [26].

In this paper aspects of the LADC 2007 experiment are described. The experiment was designed to characterize the three-dimensional airgun acoustic field of the primary arrival from a seismic airgun array. This included determining the tracks for the source ship and the depths for the receiving hydrophones subject to the constraints given by fixed cable lengths and hydrophone separation distances. Because it is important to know the accurate positions of the hydrophones during each shot, a positioning system was deployed. A brief description of this system is also included.

II. LADC 2007 EXPERIMENT

Following the 2003 LADC airgun experiment, LADC was asked by the Joint Industry Programme through the International Association of Oil and Gas Producers to do a more in-depth measurement to characterize the full three-dimensional acoustic field of the seismic airgun array. The permit was obtained to perform the experiment in the northwest Gulf of Mexico. The location south and east of the Louisiana and Texas coastlines is shown in Fig. 1.

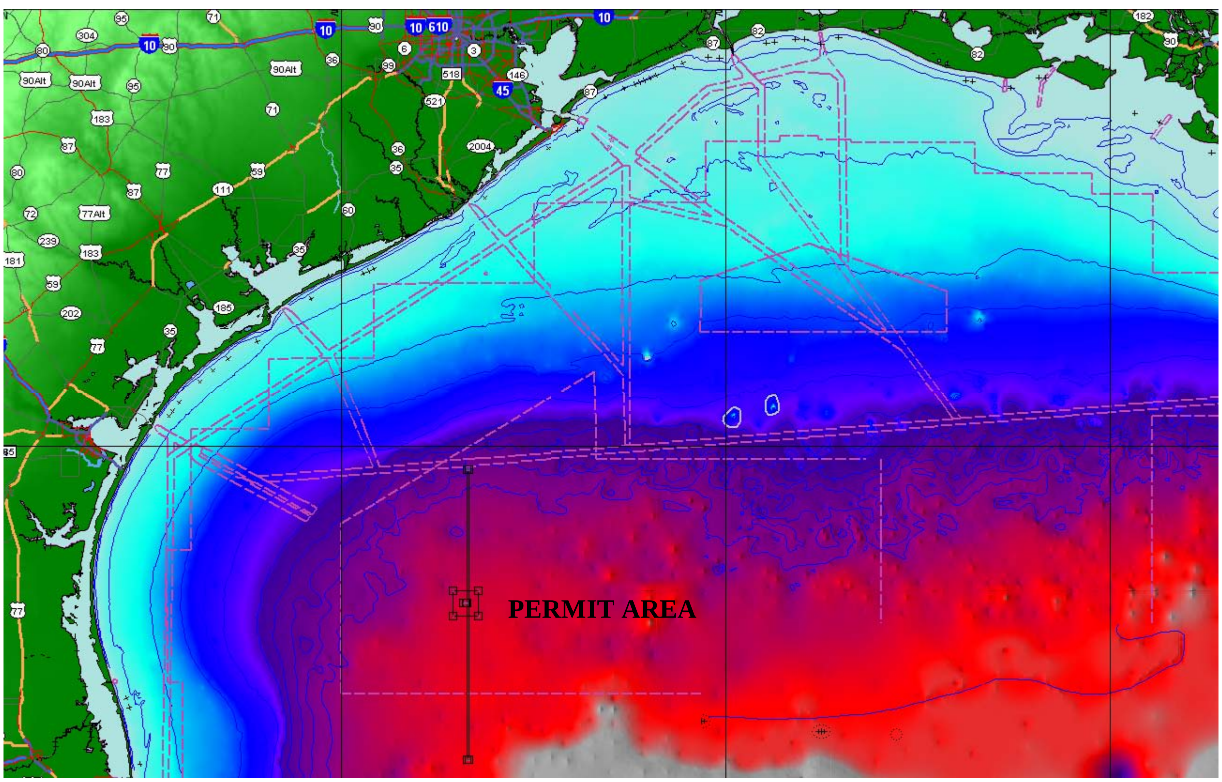


Fig. 1. Overview of the Northwestern Gulf of Mexico showing the permit area for shots, 200mi south of Houston (168nmi or 310km), 145mi southeast of Corpus Christi (125nmi or 230km). Depths are between 1500 and 1600 m. The permit area is indicated by the box and also shows the long north-south line which was collected for propagation modeling.

The experiment, Source Characterization Study 2007 (SCS07), was performed from 2 September through 22 September 2007. The source ship was the M/V Fairfield ENDEAVOR. The M/V Veritas VANTAGE provided lines of opportunity since it was in the area of the experiment. The R/V CAPE HATTERAS was used to deploy, manage, and recover the receiving hydrophone arrays. The acquisition technology consisted of calibrated Generation 2 4-channel EARS buoys developed by NAVOCEANO.

Each channel is capable of measuring to 25 kHz. A total of 48 hydrophones were deployed in collocated pairs consisting of one sensitive and one desensitized phone. As in the 2003 experiment, the densensitized phones were needed to give unclipped measurements when the source array was nearby. Sixteen phones were on each of two long vertical mid-water column bottom-moored arrays, and eight phones were on a deeper vertical bottom-moored array in approximately 1500 m water depth. Photographs of the EARS buoys and associated equipment onboard ship are shown in Figs. 2 and 3. The EARS moored array plan for one of the two long moorings in LADC07 is given in Fig. 4 and the nominal deployment depths in Fig. 5.

Fig. 2. View of long mooring on deck (pre-deployment). Yellow is floatation; black cylinders are EARS buoys in frame; small yellow cylinder is USBL transponder; "winged" sensor on grate is Valeport current meter; and white-faired line is the array.

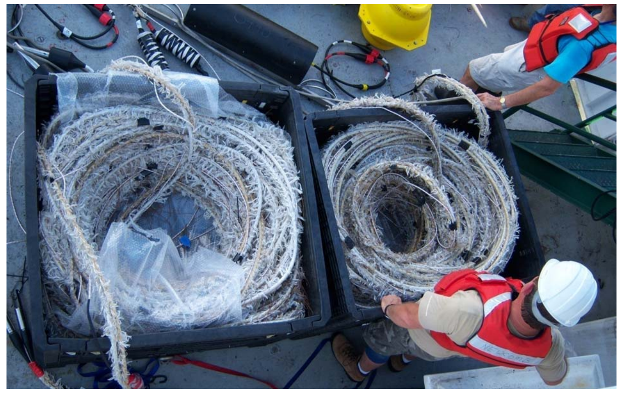


Fig. 3. Long arrays (300 m) in shipping boxes deployed directly from boxes due to limited deck space. The two cylinders next to the EARS bottle are the pre-amplifiers for the hydrophones.

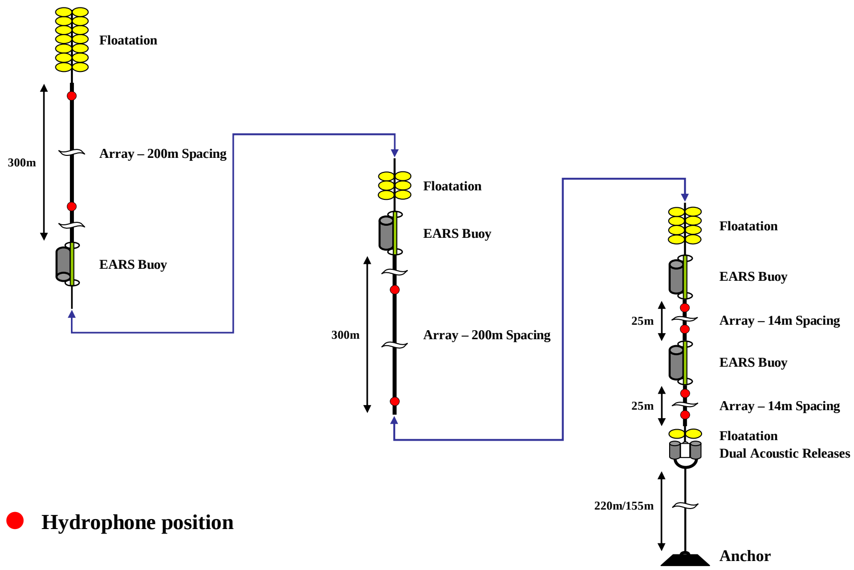


Fig. 4. Four EARS buoys inline. Red dots are hydrophone locations. Large hydrophone separation (200m) in upper arrays. Smaller hydrophone separation (14m) in lower arrays. Short mooring (without ADCP) is similar to lower right with two EARS and acoustic releases. Line below releases determined by bottom depth and desired hydrophone placement. Floatation distributed to reduce drag. The plan view for the deep hydrophone mooring looks the same as the lower mooring here, except phone spacing is 7 m instead of 14 m.

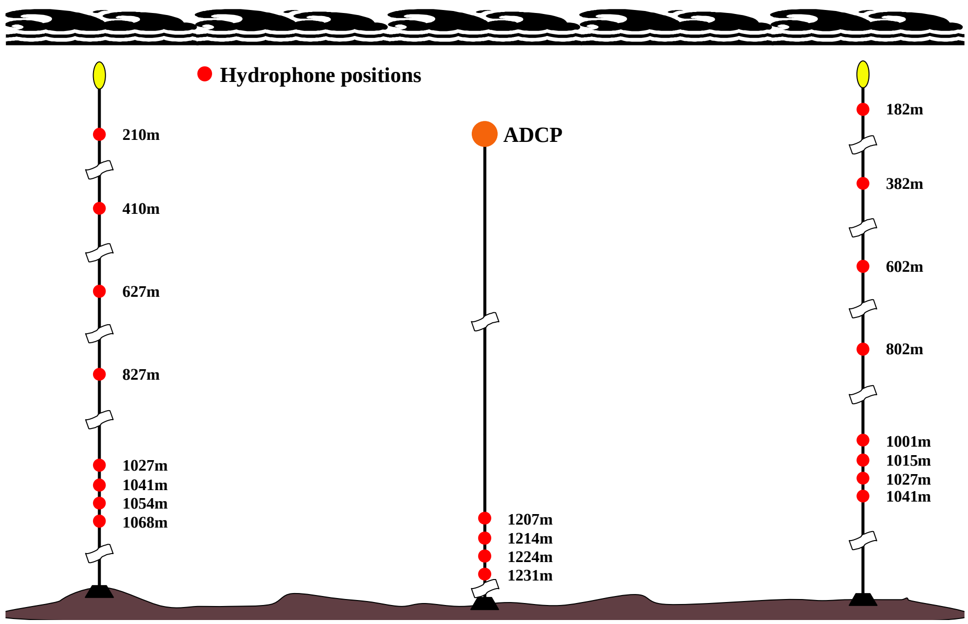
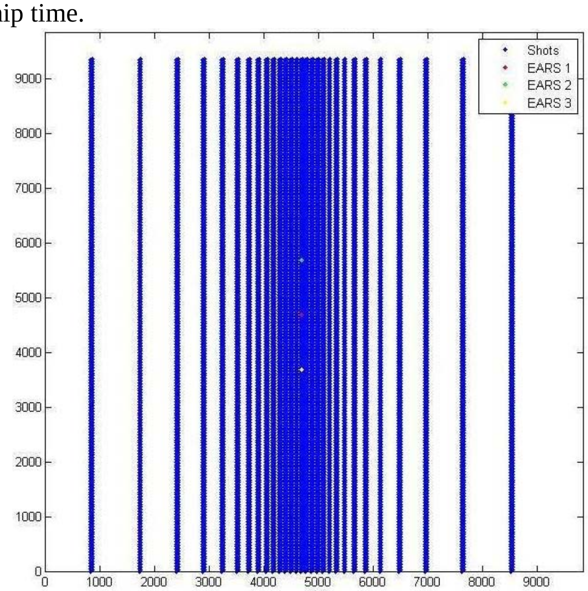


Fig. 5. The depths given are nominal depths. The deep sensors are well below the lower phones of the others.

An additional eight hydrophones were on a vertical array deployed from the HATTERAS near the surface. Every channel is calibrated. The ENDEAVOR shot a pattern of parallel lines over a small rectangle with closely spaced lines contained inside a larger rectangle with less closely spaced lines contained inside a still larger rectangle with even more spacing between the lines, as shown in Figs. 6 – 9. The largest rectangle is divided into two sets of lines with six degree spacing, one even numbered and one odd-numbered. The odd set has a trapezoidal cutout to reduce the redundancy of shots in the sail direction and save source ship time.



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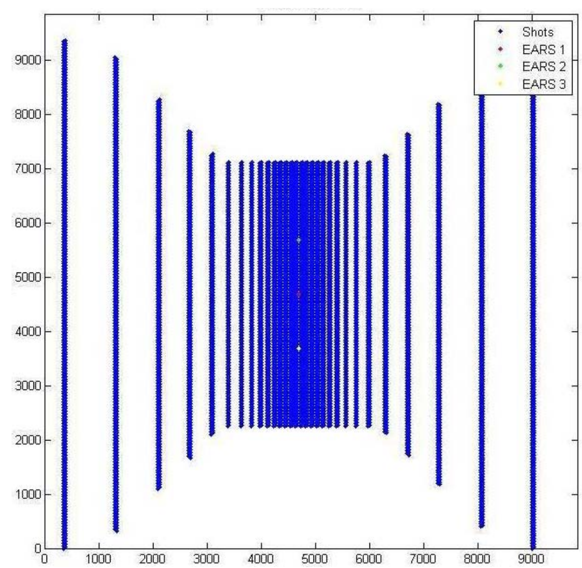

Fig. 6. Planned shot lines, showing the lines relative to the moorings (3 deg even lines). Tracks were extended 2 km in the sail direction to account for the offset of the moored arrays.

Fig. 7. The rest of the 3 degree lines (3 deg odd lines) showing the cutout.

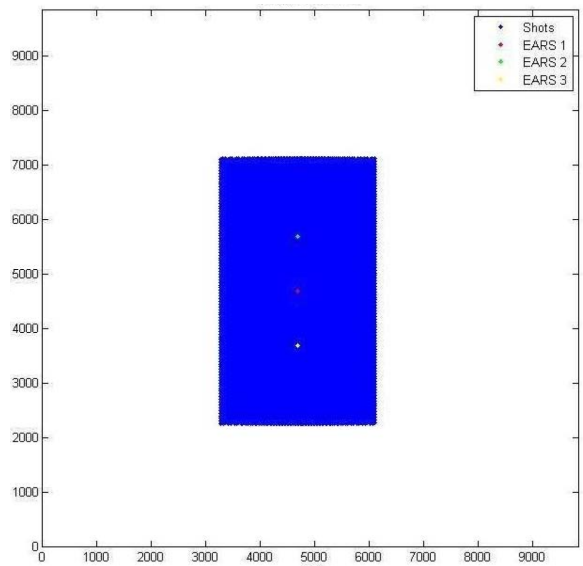

Fig. 8. Shot lines for 1 degree shots, extended by 2 km.

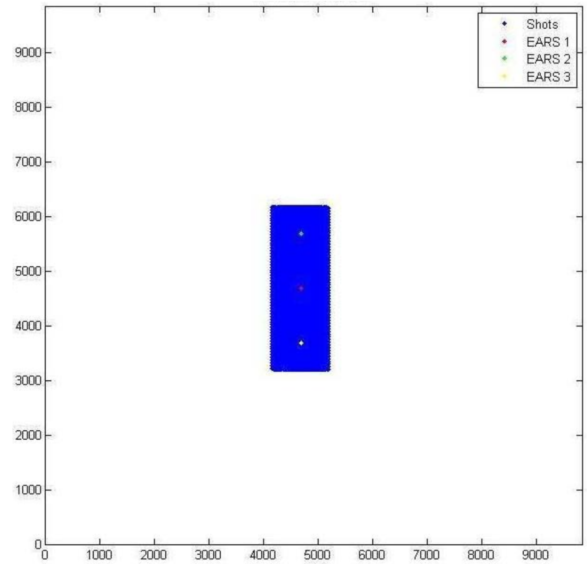

Fig. 9. Shot lines for 1/2 degree shots, extended by 2 km.

Two long perpendicular lines extending outside the rectangles (one provided by the Veritas VANTAGE) were shot for propagation analysis. The total data collected are about 3.5 TB. The ENDEAVOR shot pattern was designed to give comprehensive solid angle and range coverage so that the acoustic field could be completely characterized.

The total shot coverage in solid angle determined by the patches shown in Figs. 6 – 9 and the hydrophone placement can be specified on a spherical shell showing the number of shots at each solid angle. The range to the nearest shot at each solid angle can also be shown on a spherical shell. These are given in Figs. 10 and 11.

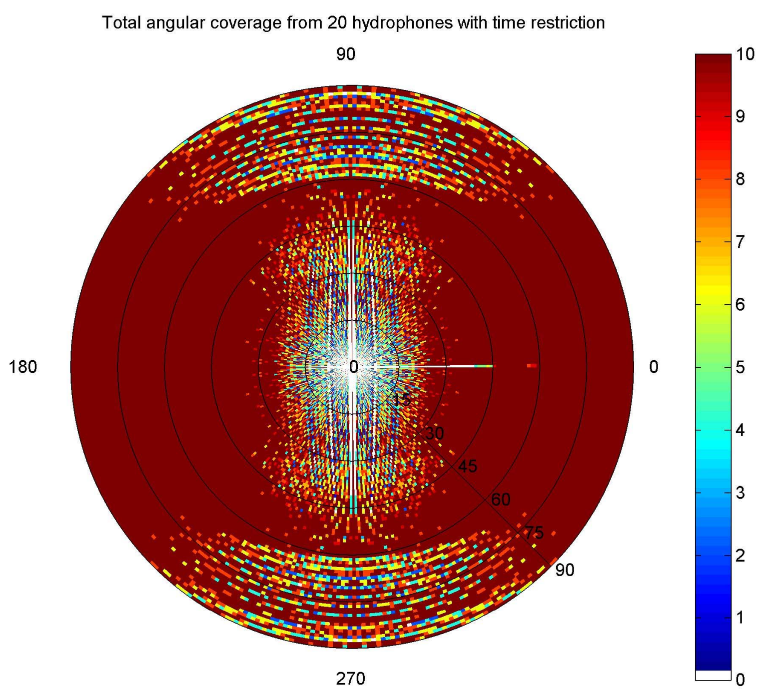

Fig. 10. Dark red corresponds to solid angles with more than 10 shots received. Lack of coverage around zero degree emission angle is due to the limitations of shot spacing (25 m) along the lines.

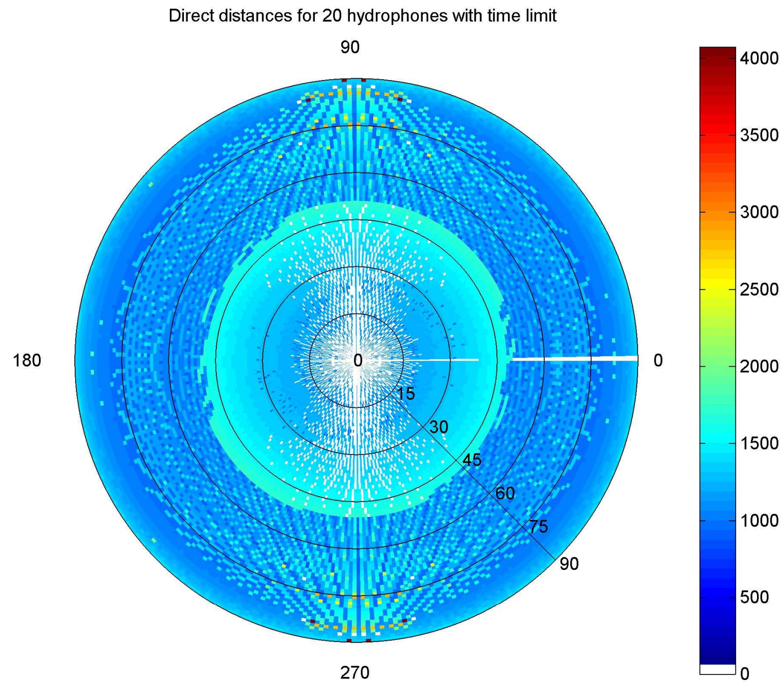

Fig. 11. Closest distance along the ray of all shots for a given solid angle. Almost all solid angles have shots closer than 2000 m. Closer shots measured by ship-mounted hydrophones are not shown but all 20 bottom-moored depths are shown.

The EARS moorings were equipped with multiple Ultra Short BaseLine (USBL) transponders, autonomous current meters, and a single Acoustic Doppler Current Profiler (ADCP). The USBL transponders were interrogated from the HATTERAS during the ENDEAVOR line changes to minimize any acoustic interference. The post analysis will provide time-dependent three-dimensional positions of each hydrophone at every seismic event.

The data analysis, now underway, includes isolating the direct arrival part of each shot and calculating properties such as maximum peak-to-peak pressures for these direct arrivals, as well as the sound exposure levels including 95% of the energy. Spectral energy versus frequency will be calculated for each shot, as well as the spectral energy analyzed into one-third octave bands. All these results will be displayed versus solid angle and range to give insight into understanding the three-dimensional acoustic field. The three-dimensional directional pattern of the array will be reconstructed for multiple frequencies. The experimental results will be modeled using source signatures generated by Gundalf and Nucleus and a range-dependent acoustic model (RAM) modified to include all the sources in the airgun array. Previous agreement of the model calculations with experimental measurements using this technique as reported in reference [1] has been good.

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